

AERODYNAMIC ANALYSIS OF COMPACT SIZE HORIZONTAL AXIS WIND TURBINE USING CFD

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ABSTRACT

A development of nation depends on harnessing of renewable energy. Wind energy is a clean source of energy and is one of the important renewable source. Wind turbines can be used to harness Wind energy. The present study deals with the computational analysis of a model of 1kW compact size horizontal axis wind turbine (HAWT) using CFD (Computational Fluid Dynamics). The wind turbine rotor configuration has been obtained using BEM (Blade Element Momentum) theory. A three-dimensional computational model of the rotor system was created and CFD simulations have been carried out using commercial CFD code solidwork flow simulation. The analysis has been carried out at various wind speeds in the range of 3 m/s to 9 m/s to study the variation of torque, normal force and power with wind speed.

KEYWORDS: Computational, Fluid, Dynamics, Horizontal, Axis, Wind, Turbine

INTRODUCTION

A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy. The first electricity generating wind turbine was battery charging machine installed in July 1887 by Scottish academic James Blyth to light his holiday home in Marykirk, Scotland. In India there are lots of villages still having no supply of electricity. Some of them are situated in hill areas where it is not possible to supply electricity. In hill areas the velocity of wind is more comparing to ground level. So we can use this wind to generate electricity with the help of wind turbine. Wind energy is a clean source of energy that is renewable and harnessing the green wind energy is one of the key factors for development of a nation.

There are two primary types of wind turbine, namely horizontal axis (HAWT) and vertical axis (VAWT) wind turbines, and the efficiency of each wind turbine type varies by its design and fabrication. The Turbine Components for Horizontal Axis Wind Turbine are: Blade which converts the energy in the wind to rotational shaft energy, The Tower that supports the blade and generator assembly, other equipment including generator, electrical cable and ground support equipment. Coefficient of performance C_p is called the power coefficient. C_p is the percentage of power in the wind that is converted into mechanical energy. The maximum achievable coefficient of performance C_p max is 0.59 given by Betz limit. Efficiency is the actual amount of energy that can be extracted from the wind is less than the theoretical amount of energy available with the theoretical limit being about 60%. A typical efficiency for wind turbine is about 40% which is about 40% of the power available in the area swept by the wind turbine blades.

Power Output

$$P = \frac{C_p \cdot \frac{1}{2} \cdot \rho \cdot A \cdot V^3}{2}$$

Where

C_p is the power coefficient

ρ is the density of air (1.2 kg/m^3)

R is the radius of the blade

V is wind velocity

Design and Calculation

In the present study, the power output has been considered to be 1 kW. Power coefficient is the ratio of power that could be extracted from the wind turbine to the wind power that is available. Betz defined the limit of energy extraction as 59.26%, beyond which the flow takes place around the wind turbine rather than through it. The radius was found to be 0.64m using the above mentioned parameters. Actual size model has been used for CFD analysis.

Three bladed configuration offers best balance between the aerodynamic efficiency, noise levels and blade stiffness, hence, are observed to be the most common and efficient design for HAWT. Two bladed configuration leads to lower cost, but complex dynamics around the system due to flow. In the present study, number of blades has been chosen as three. HAWT blades have been conventionally designed using airfoil sections, with thin airfoil at blade tip (for high lift to drag ratio) and thicker version of the same airfoil at the root for structural support. Airfoils commonly used in wind turbine blades are NACA 44xx and NACA 230xx series due to maximum lift coefficients, low pitching moment, and minimum drag. For the present study, NACA 4418 airfoil section has been used. The aerodynamic characteristic of NACA 4418 is given below

- Maximum lift coefficient C_{Lmax} of 1.797 which corresponds to critical angle of attack of 15°
- Lift coefficient for angle of attack of 9° is 1.405

For 3 bladed configurations λ should be greater than 4 for electrical power generation. The Tip speed ratio λ of 4.5 has been selected based on literature review. The angle of attack of 9° has been selected for blade configuration. The blade was divided into ten elements as shown in Fig 1. The angle of attack is same at all section.

The Chord (C) and the angle of relative wind (ϕ_r) of the blade at every section has been found from equations (Manwell 2009)

$$\phi = \frac{\pi}{2} \tan^{-1} \frac{1}{\lambda_r}$$

$$C = \frac{8\pi r (1 - \cos \phi_r)}{B C_L}$$

Where

$$\lambda_r = \lambda (r/R)$$

r is the radial length of element

R is the rotor radius and B is the number of Blades

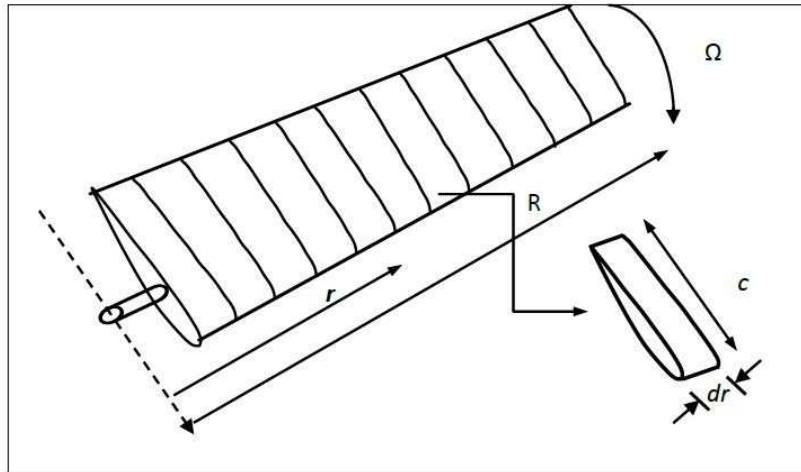


Figure 1: Schematic Representation of Blade Elements

Table 1: Igeometry of Blade

S No.	Radius R (Mm)	Chord (Mm)
1	125	140
2	189	131
3	253	115
4	317	100
5	381	88
6	445	78
7	509	69
8	573	62
9	637	57
10	701	52
11	765	48

Cfd Modelling and Analysis

The blade and the whole rotor assembly were modeled using the solidwork modeling software. The co-ordinates of the airfoil were imported into solidwork software and then connected. The blade, hub and connecting rod were created as separate volumes and were united using solidwork assembly. The modeled rotor assembly is shown in Figure 2. The problem requires modeling of rotating component (rotor and the fluid region around the rotor) and stationary part (rest of the computational domain). The analysis of the rotor has been carried out using Moving Reference Frame (MRF) technique which requires the creation of different zones of fluid for treatment in the stationary and moving reference frames.

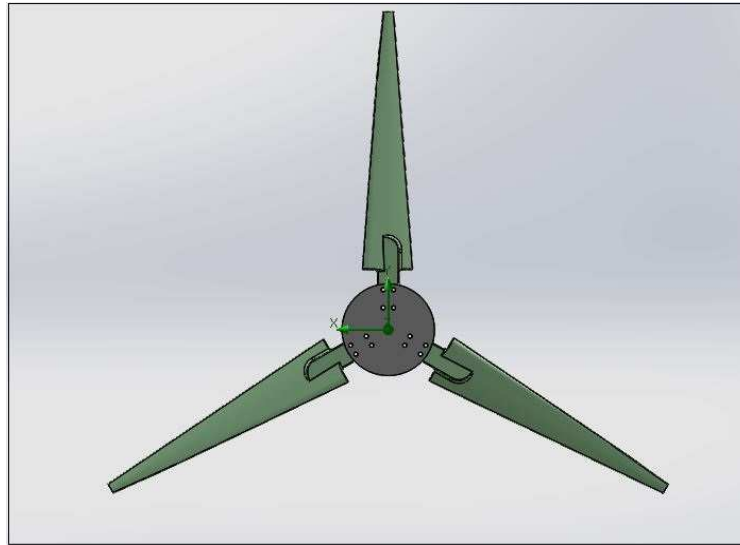


Figure 2: Modeled Rotor Geometry

A cylinder has been created around the rotor (for rotating part). The fluid passing inside this region will be analyzed using MRF technique. Outside this cylinder, another Cube has been created (stationary part). Since this is an external flow problem, the geometry that is part of the wind turbine (as a solid) is suppressed from the model. The mesh primarily consists of tetrahedral elements. Inlet Velocity has been defined as a boundary condition. The rotor faces have been assigned with zero roughness boundary condition. Inlet velocity has been given in the Z direction from 3 m/sec to 9 m/sec.

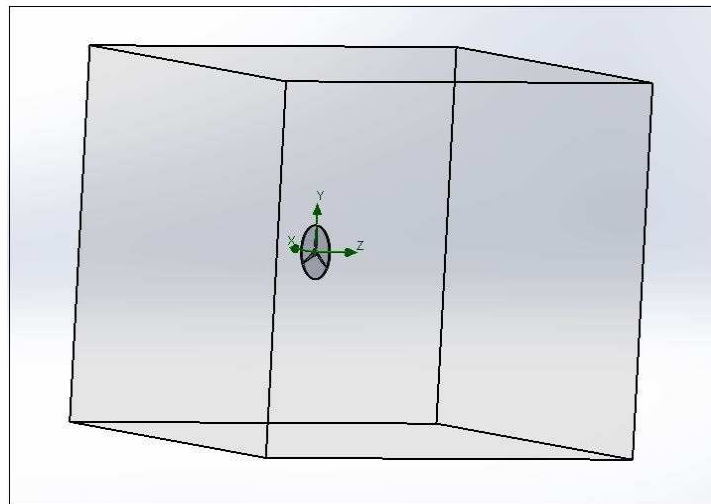


Figure 3: Computational Domain Indicating the Boundary Conditions

RESULTS

CFD simulations were carried out for different wind speeds and the performance parameters, namely normal force, torque and power were obtained. The variation of normal force, torque and power with wind speed are shown in Figures.

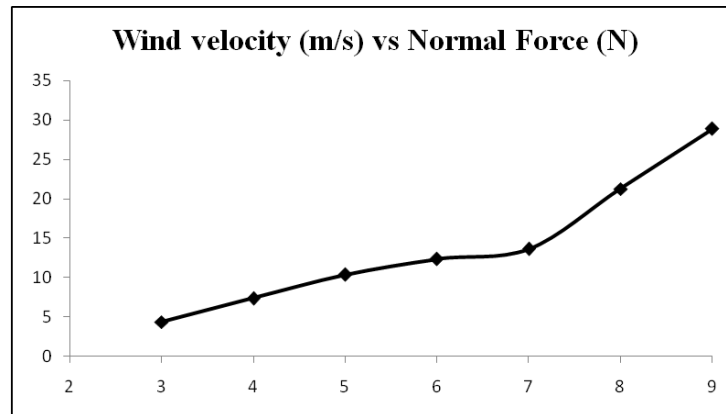


Figure 4: Variation of Normal Force with Different Wind Velocity

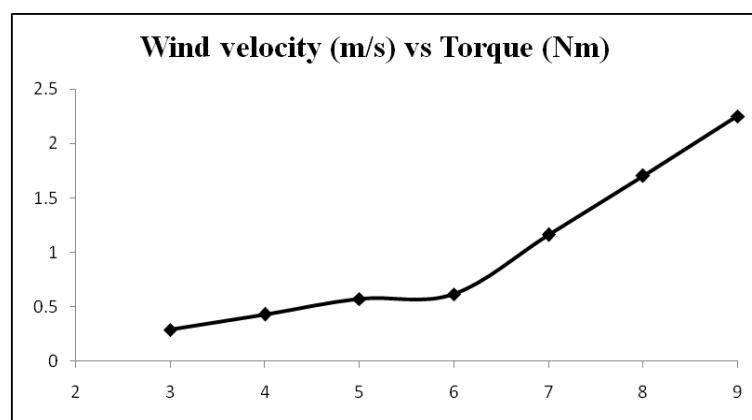


Figure 5: Variation of Torque with Different Wind Velocity

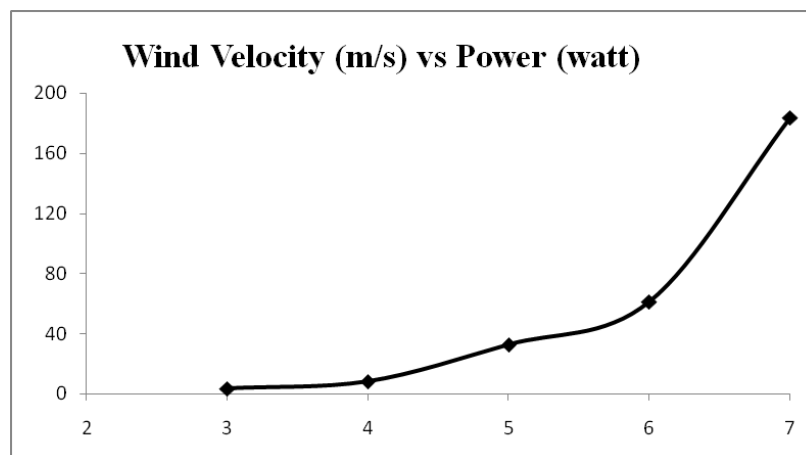


Figure 6: Variation of Power with Different Wind Velocity

CONCLUSIONS

The CFD analysis was successfully carried out using solidwork flow simulation and variation of normal force, torque and power with respect to different wind velocities has been studies successfully. The results have been validated from wind experiment (which is not included in this paper).

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